NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division

July 28, 2020

Sound Spectrum Study

Specialist's Study Report
By Sean Payne

1. EVENT

Location:	Land O Lakes, Florida
Date:	May 12, 2020
Aircraft:	Beechcraft F33A, N711JA
Operator:	Private
NTSB Number:	ERA20LA179

2. GROUP

No group was formed.

3. DETAILS OF INVESTIGATION

3.1. Accident Airplane

The accident airplane was a Beechcraft F33A. The airplane was equipped a single Continental IO 520 Series direct drive reciprocating piston engine and a 3-bladed controllable-pitch propeller.

3.2. Witness Video

A video file, "Nest Clip.mp4", was supplied to the NTSB by a homeowner. The electronic video file was received as a .mp4 file. The associated audio track was recorded at 16,000 Hz and 16-bit audio. The file was reportedly from a doorbell-type camera located at a residence in Land O Lakes, FL. The brand of doorbell camera was marked as Nest, but the specific model of doorbell camera was not documented.

3.3. Aircraft Position Data

The aircraft was equipped with an ADS-B system by the operator. The system captures the aircraft's GPS location and transmits it to the ground. Figure 1 is a plot of the ADS-B information with the witness camera location as well as the accident site marked. The ADS-B information is attached to this report as "Air Traffic Control Attachment 2 – ADS-B Data" and is provided in .CSV format.

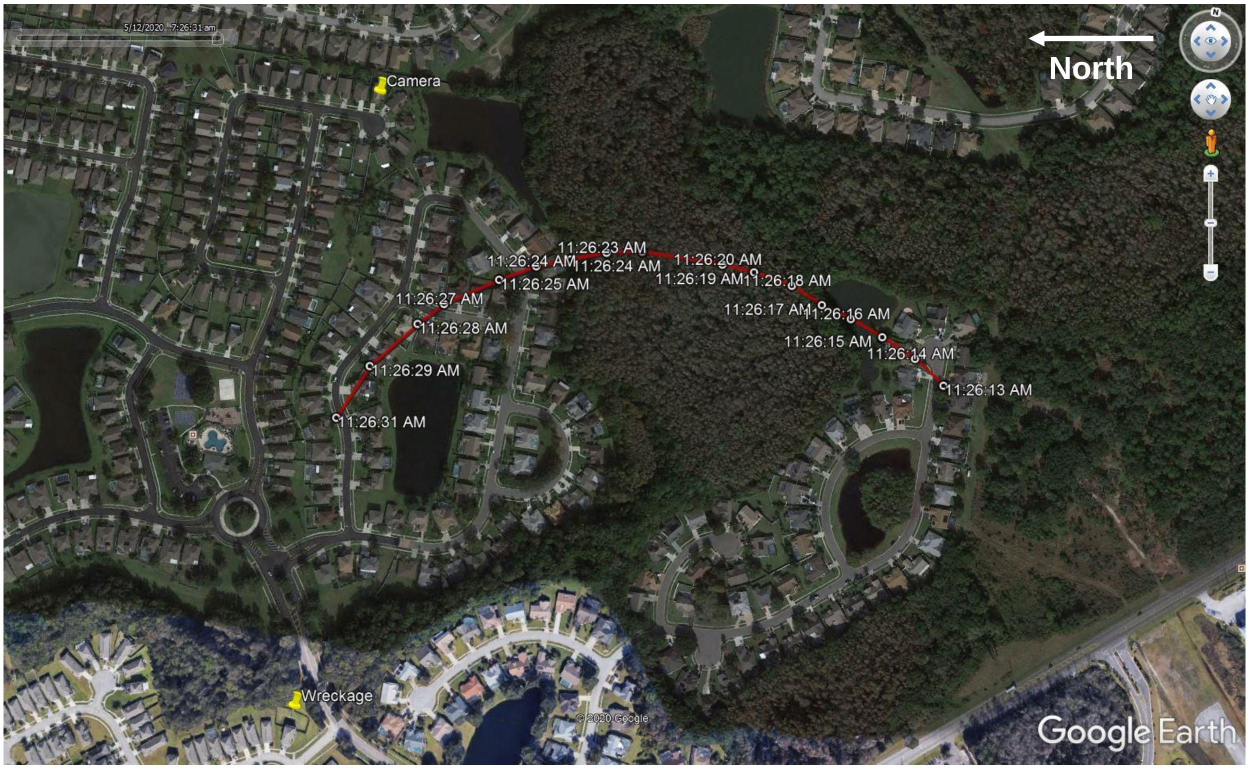

Figure 1. Aircraft flight path and location of witness video.

3.4. Calculation of Engine RPM With ADS-B Data & Audio

Because the video was not recorded with reference to any time base, a time correlation was attempted. The recovered ADS-B GPS data did not approximate the aircraft's wreckage position, and correlating the video time with the aircraft's ADS-B position was difficult. While the actual aircraft impact with the ground was not visible, a sound consistent with impact was audible. The sound of impact occurred at 2 minutes 10.8 seconds video elapsed time, however, the time of impact on the video was not obvious. Because of this, a time correlation could not be conducted.

Using the audio portion of the recording, an estimate was attempted to be made as to the aircraft's closest point of approach to the witness camera.

Speed of Sound Through Air

Equation 1 approximates the speed of sound in feet per second in still air, where γ is the specific heat ratio for air (1.4), R is the molar gas constant for air (1716 $\frac{ft*lbf}{slug*°R}$), and T is the Fahrenheit temperature. Using the 80.6° F reported temperature, the speed of sound at the time of the accident was about 1139.2 feet per second (Equation 1).

$$c = \sqrt{\gamma R(T + 459.67)} \qquad (1)$$

Doppler Effect

Because the source of engine sound is moving with respect to the witness camera, the Doppler Effect must be quantified. The Doppler Effect states that, for a source with constant emitted frequency, the measured frequency is higher than the emitted frequency as the source approaches, identical as the source passes, and lower as the source moves away. For a stationary receiver the Doppler Effect is:

$$f_S = \frac{c - v_S \cos\theta}{c} f_O \tag{2}$$

where f_O is the observed frequency, f_S is the source frequency, c is the speed of sound, v_S is the magnitude of the source velocity, and θ is the angle between the source velocity vector and the line of sight vector from the source to the sensor. To solve for the source frequency, the flightpath and velocity along the flightpath must be known.

In order to calculate the Doppler Effect, the timing of the video must be correlated with the aircraft's position. Due to the constraints of the data available in this investigation, calculating the Doppler Effect at each ADS-B data point was not possible.

Instead of calculating the Doppler Effect at each ADS-B data point, a "worst case" calculation was made and applied. The "worst case" takes the aircraft's average derived groundspeed from ADS-B data and assumes the aircraft is traveling directly toward the camera, and directly away from the camera. The doppler effect is the calculated and then applied to the RPM calculation to determine the maximum possible error.

For this investigation, the ADS-B data started being received when the aircraft was airborne, and only 17 data points were collected. The average groundspeed was calculated as 73.4 knots, which is 123.9 feet per second. Using formula 2, the maximum frequency shift for the aircraft approaching the camera was $1.10f_O$, and the maximum frequency shift for the aircraft moving away from the camera was $0.89f_O$.

Observed Frequency Determination

A spectrogram is a 3-D plot displaying time on the x-axis, frequency on the y-axis, and sound intensity in color. It is a simple way to show differences in intensity with respect to time and frequency. Figures 2 shows a spectrogram for the period of time preceding the accident. Only some points calculated are shown. For the full set of calculations refer to Table 1.

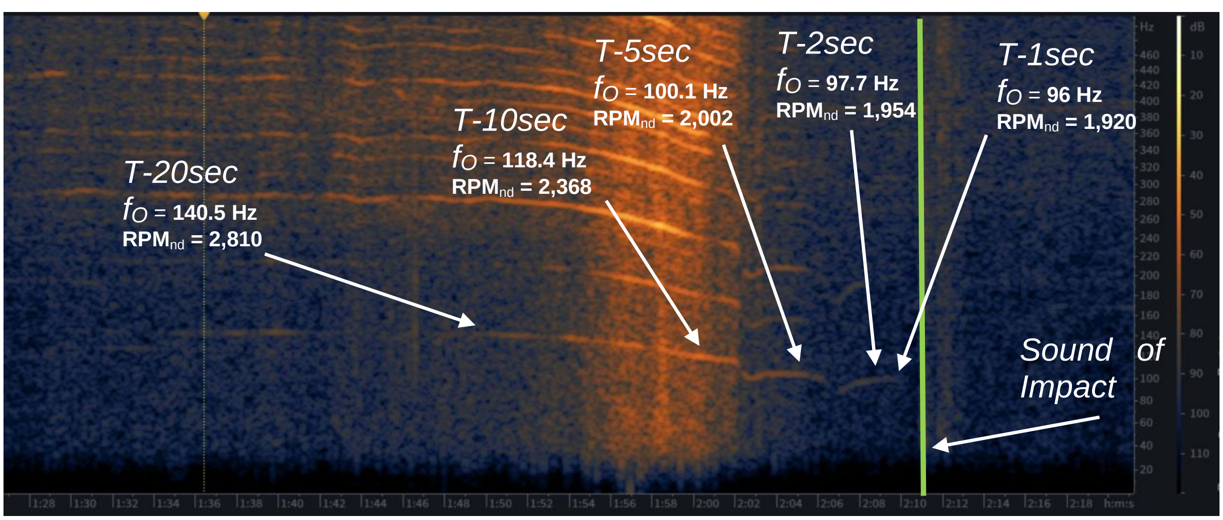

Figure 2. Spectrogram from witness video audio track. The observed frequency as well as the calculated RPM without respect to the Doppler effect is annotated.

The Doppler equation was solved for the maximum and minimum effect as described above. A value for $1.10f_O$ was used for a worst case scenario of the aircraft approaching the camera, and a value of $0.89f_O$ was used for a worst case scenario of the aircraft moving away from the camera.

Finally, Blade passage Frequency (BPF) was calculated. Equation 4 is a calculation of BPF taking into account the aircraft's three propeller blades and results in the aircraft's propellor RPM.

$$\frac{BPF}{3} * 60 = RPM \tag{4}$$

Table 1 is the result of the above calculation methodology. A sound consistent with the aircraft's impact with terrain was recorded at 2 minutes and 11 seconds elapsed time Time is given in seconds prior to the accident. $\boldsymbol{f_O}$ is the observed frequency, this is measured on the spectrogram. RPM_{nd} is the calculated propellor RPM without respect to the Doppler Effect. $\boldsymbol{f_{st}}$ is the calculated frequency with respect to the "worst case" scenario considering the Doppler Effect if the aircraft approached the camera. RPM_{st} is the calculated propellor RPM considering the Doppler Effect if the aircraft approached the camera. $\boldsymbol{f_{sa}}$ is the calculated frequency with respect to the "worst case" scenario considering the Doppler Effect if the aircraft moved directly away from the camera. RPM_{sa} is the calculated propellor RPM considering the Doppler Effect if the aircraft moved directly away from the camera.

Table 1. Propellor RPM Calculation Table

Time	f_O	RPM_{nd}	f_{sa}	RPM_{sa}	f_{st}	RPM_{st}
T-1	96	1920	105.6	2112	85.44	1708.8
T-2	97.7	1954	107.47	2149.4	86.953	1739.06
T-3	96.1	1922	105.71	2114.2	85.529	1710.58
T-4	86	1720	94.6	1892	76.54	1530.8
T-5	100.1	2002	110.11	2202.2	89.089	1781.78
T-6	102.4	2048	112.64	2252.8	91.136	1822.72
T-7	104	2080	114.4	2288	92.56	1851.2
T-8	101.1	2022	111.21	2224.2	89.979	1799.58
T-9	114.4	2288	125.84	2516.8	101.816	2036.32
T-10	118.4	2368	130.24	2604.8	105.376	2107.52
T-12	124.9	2498	137.39	2747.8	111.161	2223.22
T-14	129.8	2596	142.78	2855.6	115.522	2310.44
T-16	136.3	2726	149.93	2998.6	121.307	2426.14
T-18	138.8	2776	152.68	3053.6	123.532	2470.64
T-20	140.5	2810	154.55	3091	125.045	2500.9

3.1. Discussion

The data resulted in an RPM calculation with respect to the Doppler Effect. During the time period from T-20 (1 minute and 51 seconds elapsed) and T-9 (2 minutes and 2 seconds elapsed), the sound frequency information slopes gradually downward, suggesting the propellor RPM was somewhat stable, and the decrease in sound frequency information was likely attributed to Doppler Effect as the aircraft indirectly approached the camera.

The sound signature in Figure 2 between 2 minutes and 2 seconds elapsed and 2 minutes and 10 seconds elapsed (the sound associated with the aircraft's impact) shows a quick drop in sound frequency in two areas. Sharp drops between these two data points are likely not due to Doppler Effect from aircraft motion. These two areas of drops in sound frequency are followed by an increase in sound frequency information. These areas of drops in frequency are depicted in figure 4 as the "dynamic areas." This dynamic area is likely not attributed to the Doppler Effect. A change in sound trace in this area could be due to a dynamic actual engine RPM change, a change that occurred quicker than an estimated Doppler effect related to aircraft motion could have produced. The dynamic change could have produced a sound similar to two distinct engine "surges." Due to the limitations of these data, these dynamics were not calculated. Figure 4 illustrates the two areas of dynamic RPM change.

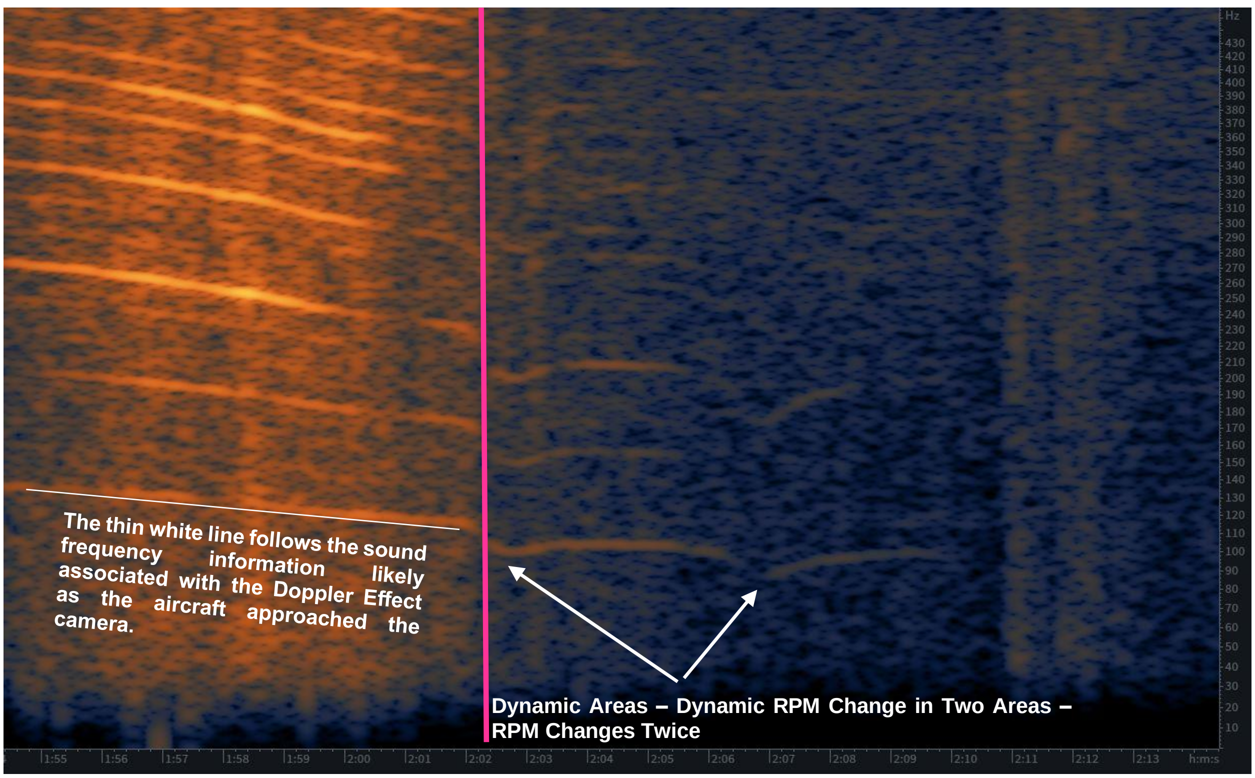

Figure 4. Graphical representation of source

3.2. Summary

A sound spectrum study was performed to determine the engine speed from recorded audio from a witness on the ground at the time of the accident. Because the aircraft was moving relative to the witness at the time of the accident, the Doppler frequency shift was approximated. The calculations showed RPM remained above at least 1700 RPM. When viewing the sound trace in the spectrogram, the RPM likely changed dynamically twice in the final portion of the audio recording. These two dynamic changes could have been interpreted by an observer as a sound similar to an engine surge.

The result of the maximum and minimum effect the Doppler effect had on the calculations, and an examination of the rate of change the Doppler effect had on the observed frequency as the aircraft changed position, show that the “dynamic areas” were likely the result of a physical RPM change on the aircraft, and not a result of the influence of the Doppler Effect. Based on the results of the Doppler shift calculations, the change in RPM in the “dynamic areas” exceeds the effect the Doppler shift had on the calculations.